Range-Dependent Acoustic Propagation in Shallow Water with Elastic Bottom Effects

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LONG-TERM GOALS

The long-range objectives of this research are to develop efficient accurate tools for quantitative forward modeling in range dependent, bottom-interacting acoustic propagation including sediment anisotropy and anelasticty.

OBJECTIVES

The specific objectives of this research are to develop practical theoretical and software tools for employing a fully elastic version of two-way coupled modes for modeling seismo-acoustic signals in shallow water with realistic elastic bottom properties, that may extend to elastically anisotropic sediment cover.

The work under award #N00014-11-1-0208 and award #N00014-11-1-0208 has been carried out with the collaboration of Dr. Scott Frank, Marist College, NY, and Dr. Jon Collis, from the Colorado School of Mines. Both were funded separately, and are not covered by this report.

APPROACH

The Call for Planning Letters suggested interest in acoustic frequencies as low as 10 Hz. This frequency corresponds to a wavelength of 200 m for a sediment compressional speed of, say, 2000m/s. At such low frequencies acoustic penetration into sediments is significant. Elastic effects (shear) cannot be ignored. In addition ocean sediments are often elastically anisotropic by the very mechanisms by which they are formed. If the anisotropy is significant, horizontally polarized shear waves (SH) can be generated even from an explosion source in the water. This conversion to SH is required by the boundary condition at the interface between the water and sediments at the ocean bottom. The attenuation in near-bottom ocean sediments may be very high. It may be high enough that perturbation theory is inadequate for properly describing loss in shallow water acoustic propagation.

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Finally there is range dependence, which can be significant in littoral regions. This project addresses two of these shallow water issues.

Range Dependence: We know that range dependence can couple (scatter) modes. In the presence of anisotropy, range dependence and anisotropy reinforce the scattering so that all modes P-SV and SH all couple together.

Anisotropy: Our local mode model incorporates anisotropy with hexagonal anisotropy, but an arbitrary symmetry axis. By incorporating this into a time domain range dependent code we will be able to trade off the effects of range dependence and anisotropy in the modeling. Much of the trade-off work has been done locally, and appeared in JASA (Soukup et al., 2013).

WORK COMPLETED

In the last year we submitted two papers to JASA, one co-authored with former student Darin J. Soukup and Jeffrey Park of Yale, "Coupled modes, range dependence, and sediment anisotropy in shallow water acoustic propagation," This manuscript is a sequel to a previous paper on propagation in anisotropic sediments, and is currently in its second round of reviews. This work focused on the combination of anisotropy and range dependence. "Elastic parabolic equation solutions for oceanic T-wave generation," Frank et al., is also in its second round of reviews for JASA. This article documents the incorporation of seismic-like sources into the PE propagation model work important for ocean acoustic signals referred to as T-phases. Finally a survey paper on ocean acoustic noise below 100 Hz appeared in January, 2014, in the *Annual Review of Marine Science*.

RESULTS

Our work on combining sediment anisotropy and range dependence is illustrated by Figures 1 and 2. The model is a fluid layer over an anisotropic sediment layer terminated with by an isotropic basement. Figure 1. is the scattering matrix S_{qr} for a VTI medium, i.e a transversely isotropic medium with a vertical symmetry axis. There is no coupling between the P-SV modes and the SH modes as indicated by the white squares, which mean zero coupling. The primary (incident) modes are the rows, and the scattered modes are the columns.

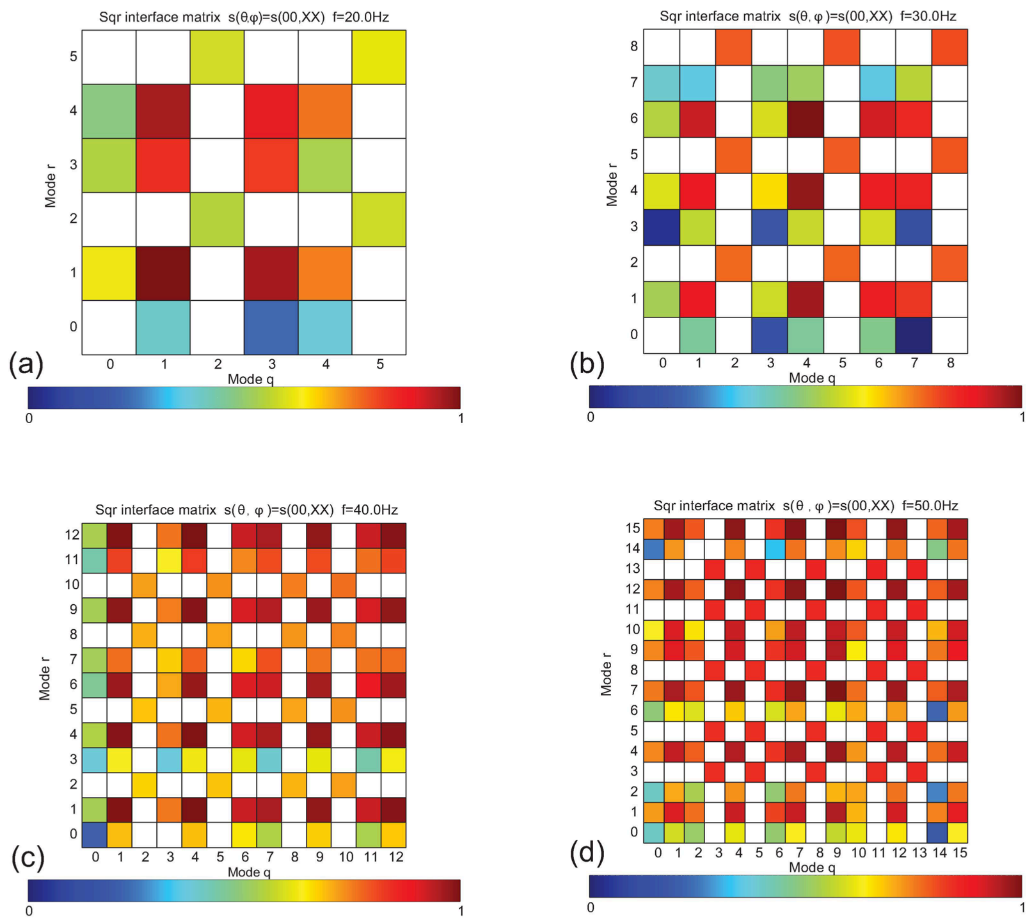

Figure 1. The scattering S_{qr} matrices for the frequencies 20, 30, 40 and 50 Hz. The white squares indicate that the coupling is zero. The SH modes do not couple to the P-SV modes. Modes are ordered by phase velocity.

Figure 2. shows the scattering matrices S_{qr} for a medium with general anisotropy, specifically a medium with a tilted symmetry axis with respect to the water-sediment boundary. In this case, the P-SV and SH modes are all coupled together. Range dependence and anisotropy together are very efficient at scattering acoustic energy. The primary modes 0, 3, and 11 are “invariant” acoustic modes, with the majority of their energy in the isotropic portion of the model. They do not contribute to the scattered wave as strongly as the more “sensitive” modes. This implies that the energy will remain coherent longer in these modes than the “sensitive" modes. However, these same “invariant” modes from the scattered wavefield receive more energy than the “sensitive” type modes. This implies that rough interface boundaries tend to preferentially redistribute energy from “sensitive” modes to “invariant” modes. The combination of range dependence and anisotropy appears to be effective at scattering a signal, and energy is redistributed broadly among all of the propagating modes. It has been demonstrated that an elastic treatment of the bottom and subbottom of the shallow water environment at low frequencies is necessary for understanding the propagation ofthe seismo-acoustic energy for tilted anisotropy.

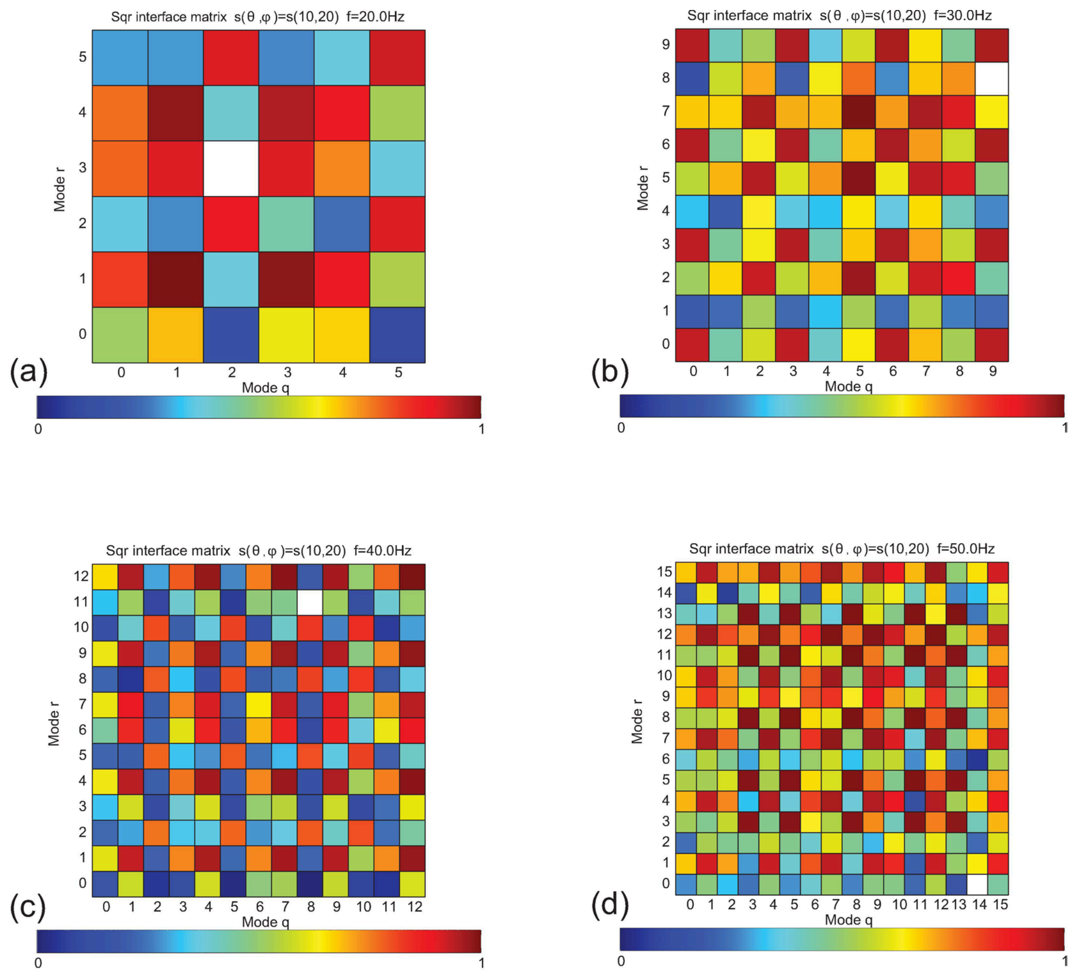

Figure 2. Scattering matrices for a medium with both anisotropy and range dependence. There are essentially no white squares indicating that all the modes are coupled together as P-SV-SH. The frequencies are 20, 30, 40 and 50 Hz. The medium is exactly the same as in Figure 1 with the only difference being the symmetry axis of the anisotropy is tilted from the vertical.

IMPACT/APPLICATIONS

This work will lead to a practical method to investigate seismo-acoustic propagation in shallow-water environments, and allow us to compare and contrast various environmental effects on the seismo-acoustic wave-field.

RELATED PROJECTS

Our research is directly related to other programs studying effects of propagation at low frequency bottom-interacting sound.

REFERENCE

Soukup, D., R.I. Odom, and J. Park, "Investigation of Anisotropy in ShallowWater Environments:A study of anisotropy beyond VTI," J. Acoust. Soc. Am., 134, pp185-206, [http://dx.doi.org/10.1121/1.4809721], 2013.

PUBLICATIONS FY14

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Soukup, D.J., R.I. Odom, and J. Park, "Coupled modes, range dependence, and sediment anisotropy in shallow water acoustic propagation," *J. Acoust. Soc. Am.*, 2013, [SUBMITTED and IN SECOND ROUND OF REVIEWS, REFEREED].

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